1930s Extent of Oak Species in the Central Sierra Nevada[1]

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Abstract

A major vegetation survey of California, the Wieslander Vegetation Type Mapping (VTM) Project, was conducted in the 1930s. Crews surveyed one-third of the state, recording detailed renditions of dominant vegetation patterns on topographic quadrangles. Documented on these maps are the dominant species of each vegetation polygon. We transformed 30,236 km^2 of the central Sierra Nevada VTM maps to digital format for use in Geographic Information Systems (GIS). We queried the resulting digital maps to develop maps of individual species in the genus *Quercus* for the region. This report presents the historical patterns and extents for five tree and four shrub species. We compared historical species' extents to modern extents, as measured by CalVeg, a modern digital vegetation map, for 16,978 km^2 of the study area. Results indicate a loss of 35 percent of historic blue oak habitat types, and an increase in montane hardwoods.

Keywords: Historic range map, landscape-scale, Quercus*, vegetation, Wieslander Vegetation Type Map.*

Introduction

The Wieslander Vegetation Type Map (VTM) Project was a United States Forest Service (USFS) effort to record California's vegetation between 1928 and 1940 (Griffin and Critchfield 1972, Wieslander 1935a, 1935b, 1985). Headed by Albert Wieslander, a silviculturist with the U.S. Forest Service California (now Pacific Southwest) Forest and Range Experiment Station, the group took more than 3,000 photographs of vegetation, surveyed more than 17,000 vegetation plots, recorded field notes, and mapped patterns of vegetation across 35 percent of the state, about 155,000 km^2 (Colwell 1977). Lands mapped were predominantly USFS lands, but extensive tracks of private land, and three national parks (Lassen, Yosemite, and Sequoia/Kings Canyon), were also included (Griffin and Critchfield 1972, Wieslander 1985). The project also collected 25,000 plant voucher specimens, which are housed at the Jepson Herbarium, University of California, Berkeley. These data

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collections are an important vegetation legacy; and all components except the vegetation maps have been digitized for preservation and are available for statewide analyses (Ertter 2000; Kelly and others 2005; plot data are available at http://vtm.berkeley.edu; photographs are available at http://www.lib.berkeley.edu/BIOS/vtm/). The vegetation maps for the central and northern Sierra Nevada have been digitized, and an effort to complete the digitization of these materials is underway (Thorne and others in press; http://cain.nbii.org/plants_animals/plants/wieslander).

The VTM project provided the foundation for much of the current knowledge of vegetation in California. Published biogeographic works include elevational transect maps of vegetation (Critchfield 1971), the distribution of California's trees (Griffin and Critchfield 1972), and the distribution of range brushlands and shrubs (Sampson and Jespersen 1963). The vegetation plot data have been used in numerous studies, including community classifications (Allen and others 1991, Allen-Diaz and Holzman 1991, Jensen 1947), and vegetation change (Bouldin 1999, Bradbury 1974, Franklin and others 2004, Minnich and Dezzani 1998, Minnich and others 1995, Taylor 2000, Taylor 2004a, b). Wieslander originally intended that the plots and vegetation maps be used together to determine extent and composition of vegetation (Wieslander 1985, Colwell 1977). This report represents an initial effort in that regard, for a limited area and theme. A number of early works also used parts of the VTM collection (Weeks and others 1934, 1943, Wieslander and Jensen 1946).

We developed GIS-compatible versions of the VTM maps for 30,236 km^2 in the central Sierra Nevada. Since individual species were recorded by polygon, we queried the digital maps for the distributions of the five important oak tree species in the region: *Quercus chrysolepis, Q. douglasii, Q. kelloggii, Q. lobata,* and *Q. wislizenii.* The VTM maps also contain information on vegetation seral condition by polygon, included in summaries presented here. We developed summary information for four *Quercus* shrub species in the region: *Q. berberidifolia, Q. durata, Q. garryana var. breweri,* and *Q. vaccinifolia.* Using VTM vegetation plot data, we examined the distribution of size classes determined by the diameter at breast height (DBH) for *Quercus* tree species for the plots in our study region. Finally, we compared the extents of some tree species with modern extents of vegetation types that contain them by using CalVeg, a map produced by the USFS in 1996 (Schwind and Gordon 2001). CalVeg did not cover the entire study area, so change was measured for the area of overlap between the maps, comprising 16,978 km^2, much of which was above the general elevation of oak tree distributions.

Methods

Development of GIS-compatible versions of the historic maps was an involved process, detailed elsewhere (Thorne and others in press). Generally the steps, in order, were: 1) scanning the original maps at 300 dots per inch; 2) scanning identical editions of the United States Geological Survey topographic maps as those the VTM vegetation maps were drawn on; 3) geo-rectifying the USGS topographic maps; and 4) registering the VTM vegetation maps onto them. Once a VTM vegetation map was geo-referenced, it could then be 5) traced using an on-screen digitizing technique that combined ArcInfo GIS software (ESRI 2006) with a WaCom tablet and digital pen (WaCom 2004). When the polygons were completed, they were 6) attributed with species codes written on the original VTM vegetation maps for each polygon. These species codes were used to 7) assign species names, using the Jepson Manual (Hickman 1993) naming conventions. Each polygon could then be 8) represented by an aggregate string of dominant plant species that each occupied at least 20 percent of the polygon's area. Finally, we 9) assigned the species aggregations to California Wildlife Habitat Relationship (CWHR) Models (California Department of Fish and Game 2004), which are habitat descriptors, using a combination of species and seral information.

We generated species-level queries to identify polygons that held any of the species of *Quercus* in them. We identified the *Quercus* position in the species string as follows: If the species was positioned first, we classed it the most dominant; if it occurred in 2nd or 3rd position, it was assumed less prevalent; and if it occurred after (4th-6th position), it was assumed still less dominant, relative to the species listed before it. Once the polygons containing each *Quercus* species were identified, they were used for summary and map production purposes (*table 1*, *figs. 1-6*). VTM crews recorded when a polygon's vegetative cover was low, due to either recent burning or recent logging. We incorporated these values to determine how much of each species' extent was in early seral condition. Using the CWHR classes we derived, we were able to assess the percent of each tree species that was resprouting and was in a chaparral condition. We counted the number of polygons each species occupied.

Finally, we derived an elevation distribution by sampling a digital elevation map using the centroid of each polygon. We used a 30-m digital elevation model that had been smoothed to a 250-m cell size using the focal mean command (ESRI 2006). The coarser resolution was used because a preliminary effort to register topography underlying the Placerville quadrangle VTM vegetation map to a modern digital topographic map surveyed using aerial images indicated spatial inaccuracies of up to 270 m, although in many places the error is lower. This level of spatial error is slightly higher than that found by Kelley and others (2005) in their study of the VTM plots. Since we wanted an average elevation for each polygon, we reasoned that resampling the elevation map was an appropriate way to smooth the elevations and obtain a reasonably accurate estimate of elevation.

We downloaded the VTM vegetation plot data files from the UC Berkeley Web site, combined the geographic file with two species files provided, and built queries to select all plots that had species of the genus *Quercus* in them. This subset of plots was then reduced to those plots in our study region. We characterized the general size distribution and height class for oaks species using the plot data. Percent of each species in each DBH size class was multiplied by the area occupied by each species in polygons to derive a landscape estimate of the area in different size classes. We felt this approach was valid because of the high number (> 200) of plots containing most species, and the fact that the VTM crews sampled vegetation with plots to represent the condition of that vegetation on the landscape (Wieslander field methods unpublished). Subsequently, we intersected the plots with *Quercus*-occupied polygons in a GIS, using a 20-m buffer. We recorded the proportion of plots to polygons for each species, examined congruence between species recorded in plots and those recorded in polygons, and determined the percent of plots that occurred in polygons with matching *Quercus* species. We compared elevation distributions obtained from the polygons with those obtained from plots for each tree species.

We compared the total extent of different *Quercus*-containing CWHR types between the VTM and the CalVeg map. Because of the spatial accuracy issues with the older data, we did not intersect those maps to show where change had occurred.

The tabular comparison permits a sense of the magnitude of change, and was only possible for oak species that were identifiable in the CWHR classes, a subset of all the species originally mapped.

Results

1. VTM Map Summaries

Oak species were found on 7,744 km^2 of the study region, in 14,941 polygons (*table 1*). Of that terrain, 21.7 percent (1,683 km^2) and 9 percent (697 km^2) were in early seral condition due to recent fires or logging, respectively. We measured the proportion of each tree species estimated to be resprouting, and in shrub form, by compiling the CWHR chaparral classes developed for each polygon (*table 1*). *Q. kelloggii, Q. lobata,* and *Q. douglasii* had less than 10 percent of their area in chaparral types, while the resprouting shrub form of *Q. wislizenii* was 25 percent. For tree species, most of the recently burned area was classed as chaparral (67 to 89 percent). The same was true for shrubs, excepting *Q. vaccinifolia*, which grows at higher elevation, and was classed as a chaparral type only 54 percent of the time, and for which only 25 percent of the area burned was classed as chaparral.

Q. douglasii was the most widely distributed tree, covering 3,132 km^2. *Q. garryana* was identified in only two polygons, and is excluded from map summaries. We present maps for six species containing enough extent to map (*figs. 1-6*), and report the elevation distribution of each species by quartile (*table 1*).

2. VTM Plot Summaries

There were 5,276 VTM vegetation plots in the study area, of which 1,628 contained species in the genus *Quercus* (*fig. 7, table 2*). Shrubs were generally not well sampled by the plot data, with only *Q. vaccinifolia* providing enough samples to be useful in generalizing to landscapes. There were no plot records for *Q. berberidifolia*, four for *Q. durata*, and 19 for *Q. garryana breweri*; these species were excluded. Of each tree species, between 64 and 84 percent were in the smallest DBH class, while 10 percent of *Q. lobata* was in the largest class, more than 91 cm DBH. From 5 to 25 percent of all tree species were in the second size class (*table 2*).

The overall elevation distribution of *Quercus* in VTM plots ranged from 7 to 2,865 m. We broke this distribution into quartiles and identified the percent plots in each class for each species (*table 2*). *Q. wislizenii* had the broadest elevation distribution, with 49 percent in the lowest elevation but 18 percent in the highest. *Q. chrysolepis* also had a broad elevation distribution, extending upslope with 31 percent in the highest elevation class. Tree height was relatively evenly distributed among height classes, with the exception of *Q. lobata*, which had few trees in the middle categories.

3. Combined Map/Plot Summaries

The most heavily sampled tree was *Q. kelloggii*, which was recorded in a plot for every 305 ha of terrain that VTM vegetation maps showed as having black oak. *Q. vaccinifolia* had a sampling ratio of one plot per 261 ha *(table 3*). *Q. douglasii* had the lowest sampling ratio, appearing in plots once for every 685 ha.

We classed each species' elevation distribution as measured by polygon centroids into the elevation quartiles defined from the VTM plot data. Comparison of elevation distributions derived from the plot and polygon data independently showed good agreement between the two data sources (*table 3*). *Q. wislizenii* is the only species that showed a difference; with 18 percent shown in the highest elevation break as measured by polygons, and only 0.8 percent registered in the plot data. The general registration of plots into polygons was tested by examining the proportion of plots whose *Quercus* species were also identified in the polygon it occupied. Only two of the five tree species had more than 50 percent of the plots correct by this measure. We therefore did not do further work with the plot/polygon combined files.

4. VTM Comparison to Modern Map Summaries by Table

Twenty-three CWHR habitat types in the CalVeg map were associated with *Quercus* species. We reduced these to 11 classes each containing a unique combination of potential *Quercus* species, for which we could calculate changes in extent (*table 4*). These changes do not represent all changes on the landscape (Thorne and others in press). *Q. douglasii* is a measurable species, and has lost 837 km^2 of extent in the region, predominantly replaced by California annual grasslands. *Q. kelloggii* occurs in many habitat types. In its association as a subdominant under conifers, it lost 1,493 km^2 (25 percent of its range). However, while the dominant overstory appears to have been lost, *Q. kelloggii* appears to have maintained extent via gains in montane hardwood and montane hardwood-conifer. These gains may also have been beneficial for *Q. chrysolepis* and *wislizenii*. Changes under 100 km^2 are probably below the resolution of both the maps and the taxonomic classification to identify, so positive change identified for *Q. lobata* is likely an error, associated with the finer mapping scale of CalVeg, which could identify much smaller stands.

Discussion

The most dominant trends measured were the decline of *Q. douglasii*, being replaced by annual grasslands, and the loss of coniferous ecosystems in which *Q. kelloggii* was a dominant understory species. The loss of 837 km^2 of *Q. douglasii*, and gain of 1,077 km^2 of California annual grasslands led to the conclusion that grasslands were the predominant landcover type to which blue oak woodlands have been converted. More detailed accounting of the changes in landcover extents by quad in the study area is in Thorne and others (in press). *Q. kelloggii* does not appear to have lost spatial extent in the conversion, but it now is represented in more polygons of montane hardwood and montane hardwood-conifer. It also appears that habitat types in which *Q. vaccinifolia* is found have been greatly reduced. Whether this has led to a decrease in this species is not clear. Changes in extent under 200 km^2 (less than 1.2 percent of the area compared for historic trends) may represent differences in mapping systems used, rather than actual change. Particularly, *Q. lobata* was indicated to have increased, while it is generally thought to be greatly reduced due to anthropogenic disturbance. Our result is likely due to the finer spatial resolution at which the modern CalVeg was mapped (1 ha minimum mapping unit, derived from 30 m satellite imagery). The finer imagery permitted the identification of smaller groups of trees, increasing the overall extent for that species.

The VTM plot data were geo-registered using a different approach than the VTM vegetation map data. The plot data were geo-registered onto historic digital topographic maps, which had already been rectified to modern imagery. The historic vegetation maps were registered to scanned 1930s versions of topographic maps, which had not been registered to modern map scans. We found that the old maps have random spatial errors of up to 270 m. We suspect that the differing registration techniques led to the poor matching of species between plot and polygon when we tried to combine them. This indicates a need for another round of processing on the VTM vegetation maps to bring them into alignment with modern topographic maps. Once that has been accomplished, it will likely result in much higher concurrence between plot and polygon species lists. The VTM mappers would survey both polygon and plot at the same time, with the objective that the plot be situated in vegetation characteristic of the polygon they had delineated (Wieslander 1985). Therefore, it is likely that many of the plots occur along the perimeters of polygons, and while they likely all described their respective polygons at the time, the differing registration techniques used made initial comparisons in GIS non-informative.

The VTM field manual recommends sampling vegetation with plots, "as often as is necessary to obtain a true picture of conditions for each vegetation type" (Wieslander unpublished), which we interpreted to mean that the data in the plots was representative of conditions by vegetation type as a whole on the landscape. The landscape sampling effort represented by both VTM plots and vegetation maps is considerable, and permitted some unification of the data without having to be spatially explicit. For example, *Q. kelloggii* appeared in VTM plot records once for every 2.5 km^2 of terrain it occupies in the VTM vegetation maps of our study area, representing 941 sample points on 2,346 km^2. All tree species, excepting *Q. lobata*, and *Q vaccinifolia*, were represented more than 200 times in the plot data (points to area mapped in *table 3*). The distribution of size classes by species in the plot data is therefore likely representative of the entire distribution of size classes by species, so we felt confident in multiplying the spatial extent of the species by the size classes to get an estimate of the proportion of landscapes in different size classes.

Elevation distribution was measured by both the polygon and the plot distributions. The distributions closely agreed, a form of validation for the historic data. An interesting question is the definition of the elevation zone within which the majority of each species occurred; narrower distributions, as seen in blue and valley oak, may be susceptible to climate change perturbations.

The VTM data permit a detailed view of the historical landscapes of California. Spatial extent, stand structure, and elevation distributions of individual species were calculated, and can be used in future landscape change analyses. Taxonomic detail in the historic data was high and spatial accuracy was moderate, with horizontal error of up to 270 m. However, when looking at landscape-level dynamics, and when reviewing tabular summaries, rather than intersected maps, trends emerged that likely reflect actual change in the central Sierra Nevada.

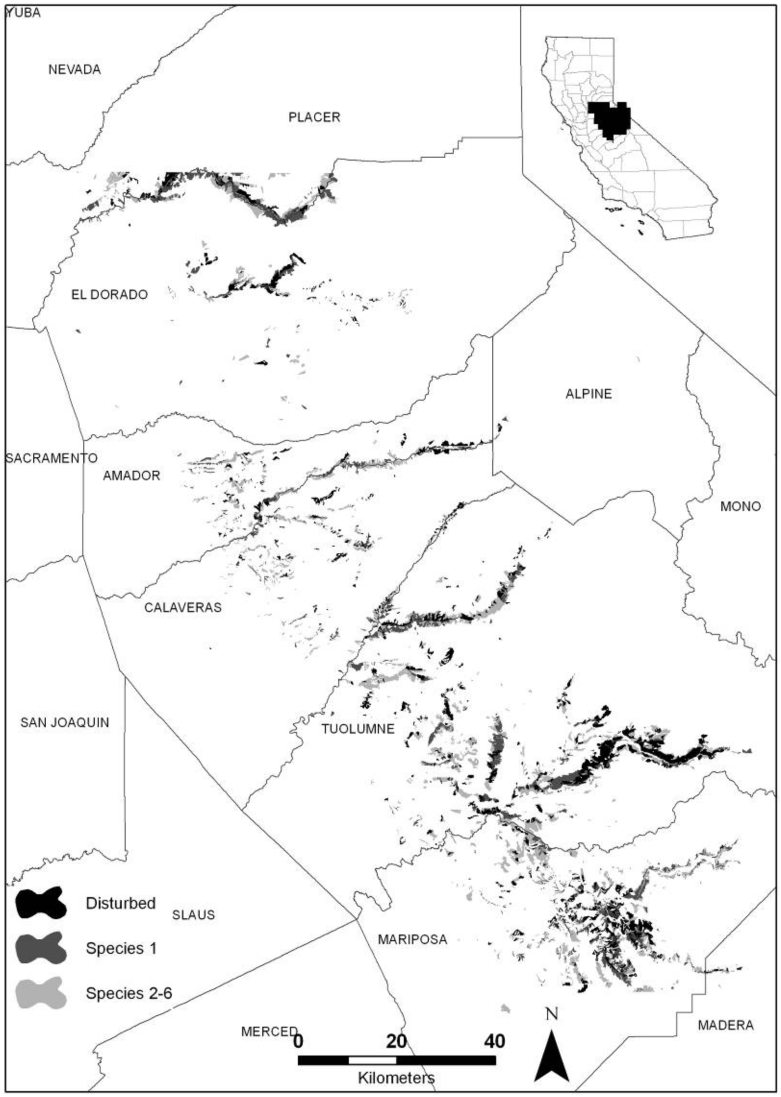

Figure 1—*Quercus chrysolepis*, the 1930s distribution of canyon live oak in the central Sierra Nevada. The species number indicates at what point the oak was recorded in the order of species listed per polygon. The less dominant species classes (species 2-3 and species 4-6) were combined for visual clarity.

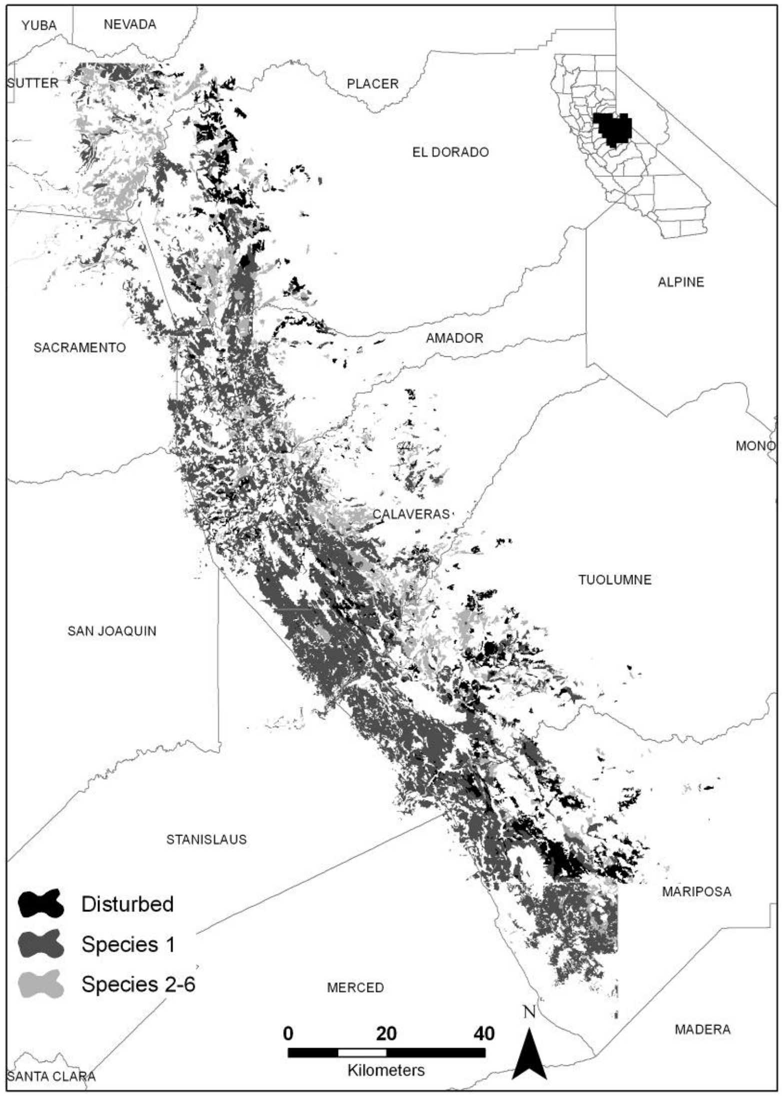

Figure 2—*Quercus douglasii*, the 1930s distribution of blue oak in the central Sierra Nevada. The species number indicates at what point the oak was recorded in the order of species listed per polygon. The less dominant species classes (species 2-3 and species 4-6) were combined for visual clarity.

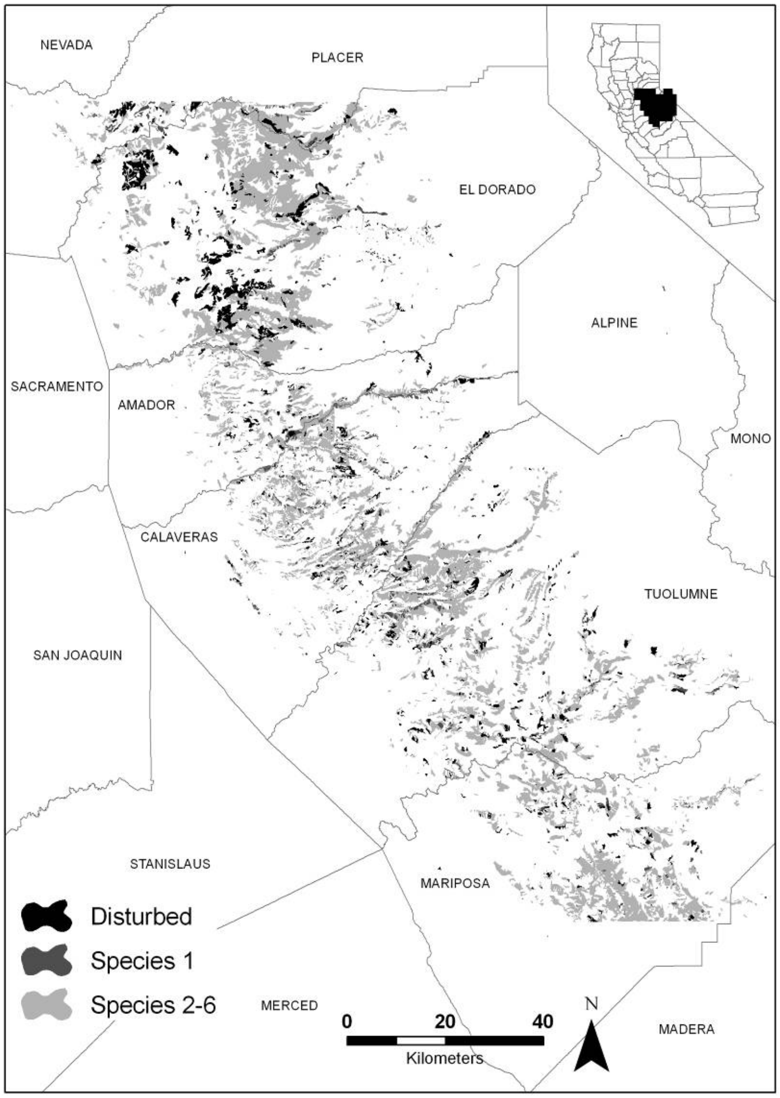

Figure 3—*Quercus kelloggii*, the 1930s distribution of black oak in the central Sierra Nevada. The species number indicates at what point the oak was recorded in the order of species listed per polygon. The less dominant species classes (species 2-3 and species 4-6) were combined for visual clarity.

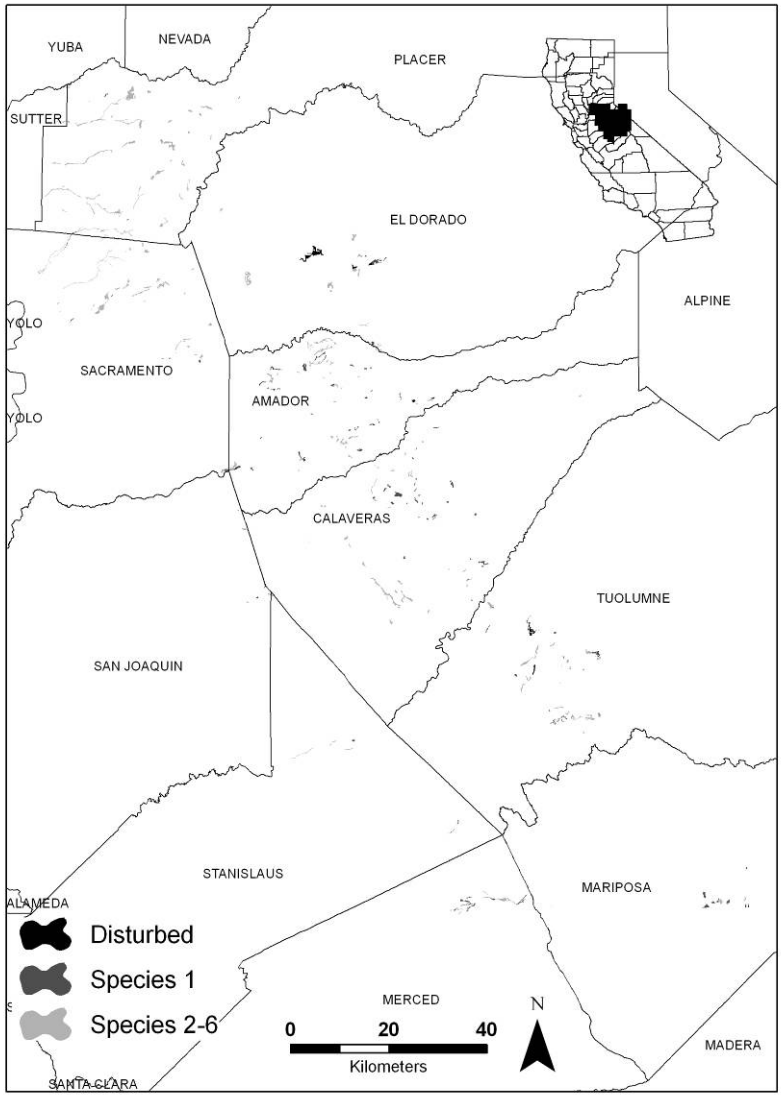

Figure 4—*Quercus lobata*, the 1930s distribution of valley oak in the central Sierra Nevada. The species number indicates at what point the oak was recorded in the order of species listed per polygon. The less dominant species classes (species 2-3 and species 4-6) were combined for visual clarity.

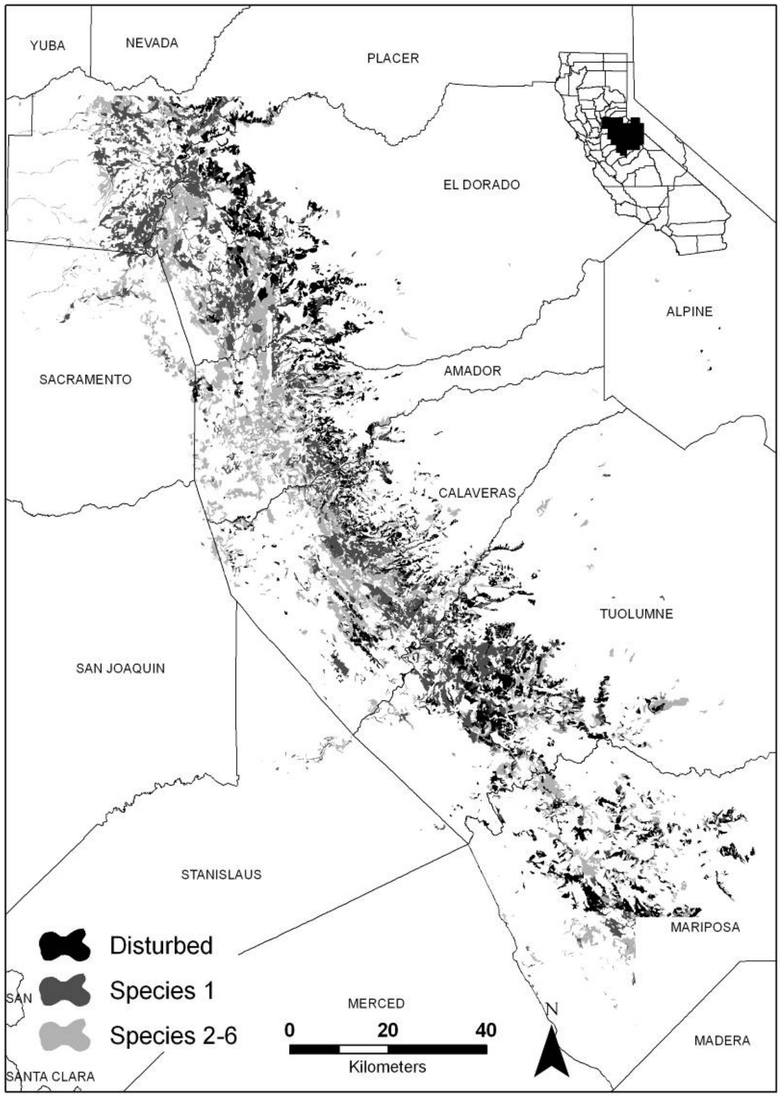

Figure 5—*Quercus wislizenii*, the 1930s distribution of interior live oak in the central Sierra Nevada. The species number indicates at what point the oak was recorded in the order of species listed per polygon. The less dominant species classes (species 2-3 and species 4-6) were combined for visual clarity.

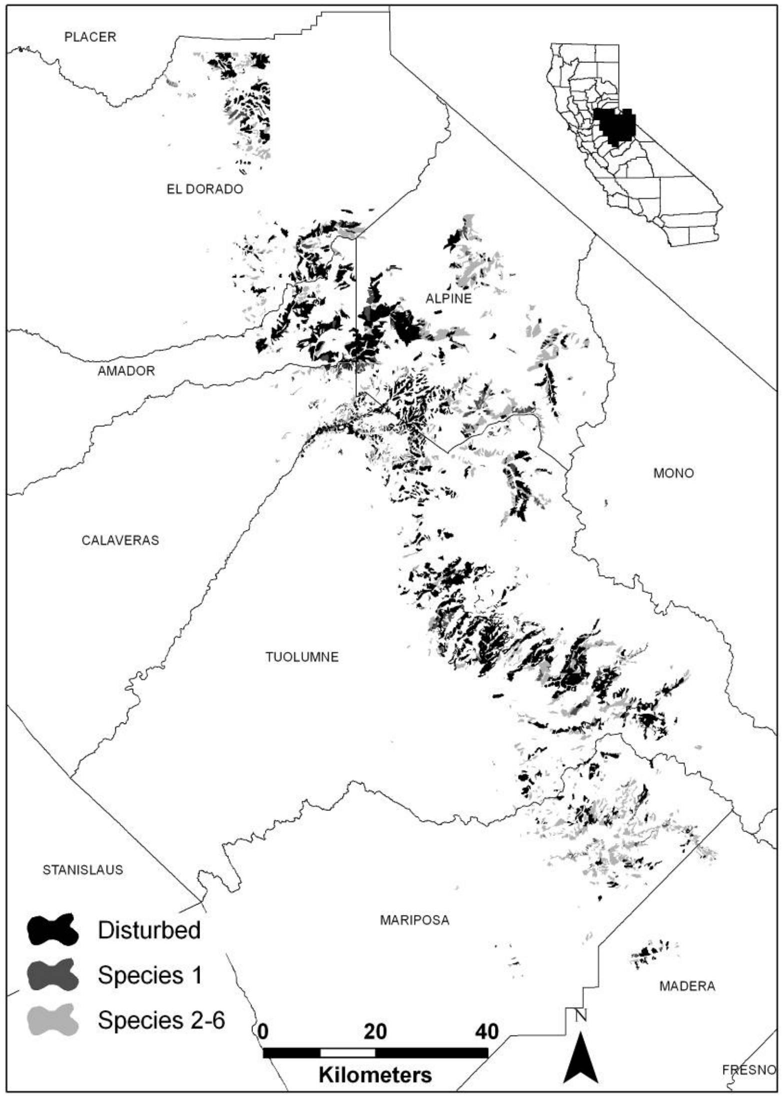

Figure 6—*Quercus vaccinifolia*, the 1930s distribution of Huckleberry oak in the central Sierra Nevada. The species number indicates at what point the oak was recorded in the order of species listed per polygon. The less dominant species classes (species 2-3 and species 4-6) were combined for visual clarity.

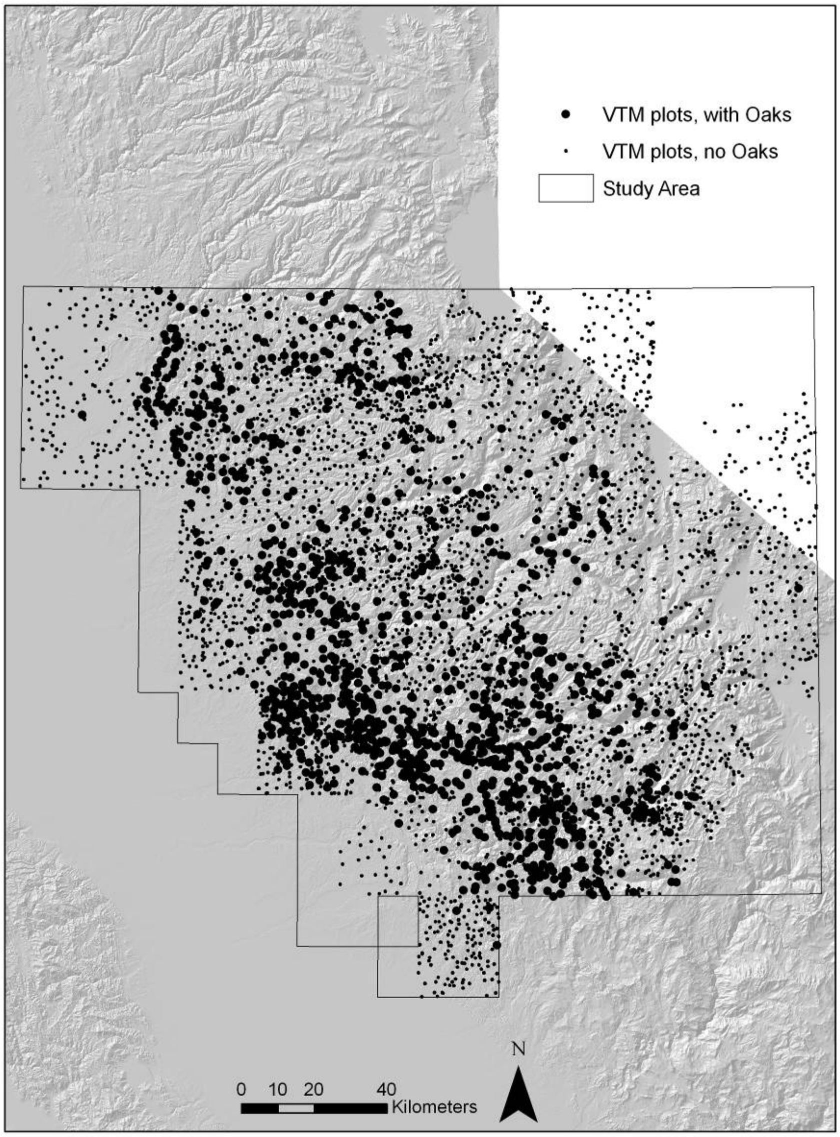

Figure 7—The distribution of 5,276 VTM vegetation plots in the central Sierra Nevada. The 1,628 plots with species in the genus *Quercus* are shown larger than those without.

Table 1—*Area extents for nine* Quercus *species in the central Sierra Nevada. The area occupied by the species in a chaparral Wildlife Habitat Relationship Type (either Mixed Chaparral or Montane Chaparral) is shown after the total extent of the type. The area of the species recently burned or logged is shown, followed by the area in which the species was listed first in the string of species; second or third; and higher; which represent different levels of prevalence by the species as compared to others it occurs with.*

Species	***Quercus chrysolepis***	***Quercus douglasii***	***Quercus kelloggii***	***Quercus lobata***	***Quercus wislizenii***	***Quercus berberdifolia***	***Quercus durata***	***Quercus vaccinifolia***	***Quercus garryana breweri***
Total Area (ha)	101,795	313,207	234,465	8,945	279,250	930	**1,647**	**100,237**	**1,613**
Chaparral Area (ha)	16,656	27,705	23,372	417	67,619	902	1,202	25,132	1,293
Total Area Burned	21,670	41,539	27,022	596	75,788	189	489	466	547
Total Area Logged	8,695	469	4,002	8	505	0	30	56,067	0
Species Listed First (ha)	46,459	225,318	21,602	2,375	142,537	242	1,017	18,853	681
Number of Polygons (SP1)	1,379	2,473	925	137	3,265	9	19	512	55
Species Listed Second or Third (ha)	47,610	86,260	190,906	5,783	131,418	666	531	65,701	710
Number of polygons (SP2_3)	1,312	1,336	3,429	189	2,305	14	7	1,620	36
Species listed 4th, 5th, or 6th (ha)	7,726	1,628	21,958	786	5,295	23	99	15,683	222
Number of polygons (SP4_5_ 6)	173	26	308	21	124	1	2	296	3
Total Number of polygons	2,864	3,835	4,662	347	5,694	24	28	2,428	94
Elevation Range (m)	548	342	622	591	330	213	185	377	215
Percent of Species Extent in Chaparral	16	9	10	5	24	97	73	25	80

Table 2— *Summary of VTM plot data for six species of* Quercus *in the central Sierra Nevada.*

Species	***Quercus chrysolepis***	***Quercus douglasii***	***Quercus kelloggii***	***Quercus lobata***	***Quercus wislizenii***	***Quercus vaccinifolia***
Number of Plots	215	457	941	44	534	261
Elevation 7- 457m (%)	3	65	6	47	50	0
Elevation 457 - 823 m (%)	25	26	20	47	27	0
Elevation 823 - 1295 m (%)	41	10	33	7	6	0
Elevation > 1295 m (%)	31	0	40	0	18	100
Diameter Class 4 – 11” (%)	83	83	67	65	80	
Diameter Class 12 – 23” (%)	6	15	26	26	12	
Diameter Class 24 – 35” (%)	4	2	6	0	7	
Diameter Class > 36” (%)	1	0	1	10	1	
Height Class 0 - 4.5 m (%)	25	17	27	73	30	100
Height Class 4.5 - 7.6 m (%)	30	46	21	0	20	
Height Class 7.6 - 10.7 m (%)	20	30	26	7	16	
Height Class > 10.7 m (%)	25	5	25	20	33	

Table 3— *Combination of historic VTM vegetation maps and VTM plot data for the Central Sierra Nevada.*

Species	***Quercus chrysolepis***	***Quercus douglasii***	***Quercus kelloggii***	***Quercus lobata***	***Quercus wislizenii***	***Quercus vaccinifolia***
Number of Plots	215	457	941	44	534	261
Ratio of Area Occupied by Species per VTM Plot with species (ha)	473	685	249	203	520	384
Number of plots correctly classed	84	344	389	2	333	
Number of plots incorrectly classed	131	113	552	42	201	
Percent Plots correctly classed	39	75	41	5	62	
Area Occupied by Each Diameter Size Class (ha)						
Diameter Class 4 – 11”	84,900	260,082	158,122	5,771	222,746	
Diameter Class 12 – 23”	5,733	4,158	6,000	108	8,183	
Diameter Class 24 – 35”	723	3	37	0	23	
Diameter Class > 36”	5	1	13	37	7	
Percent Plots by Elevation Quartile						
Elevation 7- 457m (%)	3	65	6	47	50	0
Elevation 457 - 823 m (%)	25	26	20	47	27	0
Elevation 823 - 1295 m (%)	41	10	33	7	6	0
Elevation > 1295 m (%)	31	0	40	0	18	100
Percent Polygons by Elevation Quartile						
Elevation 7- 457m (%)	4	65	9	59	43	0
Elevation 457 - 823 m (%)	25	28	32	31	45	0
Elevation 823 - 1295 m (%)	44	7	36	9	12	0
Elevation > 1295 m (%)	27	0	24	0	1	100
Number of Polygons by Elevation Quartile						
Elevation 7- 457m (#)	115	2,481	421	205	2,439	0
Elevation 457 - 823 m (#)	712	1,092	1,474	109	2,549	2
Elevation 823 - 1295 m (#)	1,260	263	1,663	32	660	6
Elevation > 1295 m (#)	776	0	1,103	1	48	2,418

Table 4— *Measure of change in* Quercus *occupied California Wildlife Habitat Relationship (CWHR) types between 1934 and 1996 in the central Sierra Nevada. Species that occur in the CWHR class are shown in parentheses*.

CWHR Classes	**VTM (ha)**	**CalVeg (ha)**	**Area Gained or Lost (ha)**
Montane Hardwood (*Q. kelloggii, chrysolepis, wislizenii*)	112,336	223,119	110,783
Annual Grassland (AGS)	180,202	287,920	107,718
Montane Hardwood-Conifer (*Q. kelloggii, chrysolepis, wislizenii*)	31,962	97,057	65,095
Mixed Chaparral (*Q. kelloggii, chrysopelis, wislizenii, durata, berberdifolia, garryana breweri*)	66,241	77,280	11,039
Douglas Fir (*Q. kelloggii, chrysolepis*)	32,122	42,046	9,924
Valley Oak Woodland & Riparian (*Q lobata, douglasii*)	2,858	3,171	313
Aspen, Eastside Pine, Subalpine Conifer, Lodgepole Pine, Red Fir (*Q vaccinifolia*)	148,096	123,006	-25,090
Montane Chaparral (*Q kelloggii, vaccinifolia, durata, berberdifolia*)	71,990	41,404	-30,586
Chamise-Redshank Chaparral (*Q durata, berberdifolia, kelloggii*)	77,387	33,243	-44,144
Blue Oak Woodland, Blue Oak Foothill Pine (*Q douglasii*)	242,208	158,460	-83,748
Ponderosa Pine, Sierran Mixed Conifer, White Fir, Jeffery Pine Montane Riparian (*Q kelloggii*)	593,983	444,603	-149,380

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